

5.8 Rock-Lined Channel Design

Rock-lined channels constructed from riprap, grouted riprap, or wire-enclosed rock can be cost effective at controlling erosion along short channel reaches. These rock-lined channels might be appropriate in the following scenarios:

- Where major flows generate velocities in excess of allowable non-eroding values.
- Where right-of-way restrictions necessitate channel side slopes to be steeper than 3H:1V.
- Where rapid changes in channel geometry occur such as at channel bends and transitions.
- For low flow channels.

For hydraulic calculations, the following equation can be used for Manning's n values for riprap (this equation does not apply to situations involving very shallow flow where the roughness coefficient will be greater):

$$n = 0.0395 (d_{50})^{1/6} \quad (5.6)$$

Where: n = Manning's roughness coefficient for stone riprap
 d_{50} = diameter of stone for which 50 percent, by weight, of the gradation is finer (ft)

A Manning's n value of 0.035 can be used for wire-enclosed rock and a value of 0.023 to 0.030 can be used for grouted riprap.

Riprap requirements for a stable channel lining can be based on the following relationship (UDFCD 1984):

$$\frac{V S^{0.17}}{d_{50}^{0.5} (S_s - 1)^{0.66}} = 4.5 \quad (5.7)$$

Where: V = mean channel velocity (ft/s)
 S = longitudinal channel slope (ft/ft)
 S_s = specific gravity of rock (minimum $S_s = 2.5$)
 d_{50} = diameter of stone for which 50 percent, by weight, of the gradation is finer (ft)

Rock sizing requirements are based on rock having a specific gravity of at least 2.5. Gradation and classification for riprap are shown in Tables 5-8 and 5-9.

Table 5-8 Rock Riprap Gradation Limits

Stone Size Range (ft.)	Stone Weight Range (lb)	Percent of Gradation Smaller Than
1.5 d_{50} to 1.7 d_{50}	3.0 W_{50} to 5.0 W_{50}	100
1.2 d_{50} to 1.4 d_{50}	2.0 W_{50} to 2.75 W_{50}	85
1.0 d_{50} to 1.15 d_{50}	1.0 W_{50} to 1.5 W_{50}	50
0.4 d_{50} to 0.6 d_{50}	0.1 W_{50} to 0.2 W_{50}	15

Table 5-9 Riprap Gradation Classes

<u>Riprap Class</u>	<u>Rock Size¹ (ft.)</u>	<u>Rock Size² (lbs.)</u>	<u>Percent of Riprap Smaller Than</u>
Facing	1.30	200	100
	0.95	75	50
	0.40	5	10
Light	1.80	500	100
	1.30	200	50
	0.40	5	10
1/4 ton	2.25	1000	100
	1.80	500	50
	0.95	75	10
½ ton	2.85	2000	100
	2.25	1000	50
	1.80	500	5
1 ton	3.60	4000	100
	2.85	2000	50
	2.25	1000	5
2 ton	4.50	8000	100
	3.60	4000	50
	2.85	2000	5

¹ Assuming a specific gravity of 2.65.

² Based on AASHTO gradations.

Rock-lined side slopes steeper than 2H:1V are considered unacceptable because of stability, safety, and maintenance considerations. Proper bedding is required along both the side slopes and channel bottom. The riprap blanket thickness should be at least 1.75 times d_{50} and should extend up the side slopes at least one foot above the design water surface. The upstream and downstream flanks require special treatment to prevent undermining. Details on these considerations are presented in section 5.11.2.

5.9 Concrete Channels

Concrete linings are used where smoothness offers a higher capacity for a given cross-sectional area. When properly designed, rigid linings may be appropriate where the channel width is restricted. Use of concrete linings is not encouraged due to the lack of water quality benefits as well as the propensity for higher velocities, which create the potential for scour at channel lining transitions.

5.10 Grade Control Structures

The most common use of channel drop structures or grade control structures is to control the longitudinal slope of grass-lined channels to keep design velocities within acceptable limits. Baffle chute drops, grouted sloping boulder drops, and vertical riprap drops are all examples of possible structures to use. The focus of this section will be on vertical riprap drops. The guidance presented in this section for design of vertical riprap drops was obtained from the City of Tulsa Stormwater Management Manual (1993). Other design approaches exist which are also appropriate for vertical drops and other types of grade control structures. For example, the reader is referred to the SCS National Engineering Handbook for more detail on chute and sloping boulder drops. Also, Chapter 7 of this Manual provides guidance for more substantial energy dissipator structures used for larger flows and channel transitions.

The design of hydraulic structures, such as drop structures, must consider safety of the general public, especially when multiple uses are allowed (i.e., boating and fishing). There are certain hazards that can be associated with drop structures, such as the “reverse roller” phenomenon which can trap an individual and result in drowning. As a result, it may be necessary to sign locations accessible by the public to warn of the danger associated with the hydraulic structure and should be evaluated on a project by project basis.

5.10.1 Vertical Riprap Drops

An example of a vertical riprap drop is presented in Figure 5-6. The design of the drop is based upon the height of the drop and the normal depth and velocity of the approach and exit channels. The channel should be prismatic from the upstream channel through the drop to the downstream channel. The maximum recommended side slope for the stilling basin area is 4:1. Flatter side slopes are encouraged when available right-of-way exists. When riprap is grouted, the stilling basin side slopes can be steepened to 3:1. The riprap should extend up the side slopes to a depth 1 foot above the normal depth projected upstream from the downstream channel. For safety considerations, the maximum fall recommended at any one drop structure is 4 feet from the upper channel bottom to the lower channel bottom, excluding the trickle channel. Table 5-10 is a design chart to be used in conjunction with Figure 5-6 for sizing of the riprap basin and retaining wall structure. Rock-filled wire baskets may be a likely alternative to be considered by the designer for some structures.

5.10.1.1 Approach Depth

The upstream and downstream channels will normally be grass-lined trapezoidal channels with trickle channels to convey normal low flow water. The maximum normal depth, y_n , is 5 feet and the maximum normal velocity, v_n , is 7 ft/s for erosion-resistant soils and 5 ft/s for easily eroded soils.

5.10.1.2 Trickle Channel

The trickle channel (shown as a concrete channel in Figure 5-6) ends at the upstream end of the upstream riprap apron. A combination cutoff wall and foundation wall is provided to give the end of the trickle channel additional support. The water is allowed to flow across the upstream apron and over the vertical wall. The trickle channel is ended at the upstream end of the apron to minimize the concentration of flows.

5.10.1.3 Approach Apron

A 10-foot long riprap apron ($d_{50} = 12$ inches is recommended) is provided upstream of the cutoff wall to protect against the increasing velocities and turbulence which result as the water approaches the vertical drop. Grouted riprap can also be used for the approach apron.

5.10.1.4 Crest Wall

The vertical wall should have the same trapezoidal shape as the approach channel. The wall distributes the flow evenly over the entire width of the drop structure, which minimizes flow concentrations that could adversely affect the riprap basin. The trickle flows pass through the wall via a series of notches in order to prevent ponding (see Figure 5-6).

The wall must be designed as a structural retaining wall, with the top of the wall above the upstream channel bottom. This is done to create a higher water surface elevation upstream, thereby reducing the draw-down effects normally caused by a sudden drop. The distance, P , that the top of the wall should be above the upstream channel, can be

determined from Table 5-10 or from a backwater analysis.

5.10.1.5 Stilling Basin

The riprap stilling basin is designed to force the hydraulic jump to occur within the basin, and is designed for minimal scour. The floor of the basin is depressed an amount, B , below the downstream channel bottom, excluding the trickle channel. This is done to create a deeper downstream sequent depth which helps keep the hydraulic jump in the basin. This arrangement will cause ponding in the basin; however, a trickle channel can relieve all or some of the ponding.

The riprap basin can be sized using Table 5-10. To use the table, determine the required height of the drop, C , the normal velocity of the approach, v_n and the upstream and downstream normal depths, y_n and y_2 , respectively. Both upstream and downstream channels must have the same geometry and y_n and y_2 must be equal to use Table 5-10. Select the appropriate riprap classification based on the row with the correct C , v_n , y_n , and y_2 . The riprap should be placed on bedding and filter fabric and should extend up the channel side slopes a distance $y_2 + 1$ foot as projected from the downstream channel. The basin side slopes should be the same as those in the downstream channel (i.e., 4:1 or flatter).

When riprap is grouted to within approximately 4 inches of the riprap surface, then the rock size requirement can be reduced by one size from that specified in Table 5-10. However, if the grout has been placed such that much of the rock surface is smooth, a larger basin than specified in Table 5-10 would be required.

5.10.1.6 Exit Depth

The downstream channel design should be the same as the upstream channel, including a trickle channel. For concrete trickle channels, a cutoff wall similar to the one used for the upstream trickle channel should be used. This may also serve to control seepage and piping.

5.10.1.7 Design Example

The following example demonstrates the use of Table 5-10 and Figure 5-6 for the sizing of riprap basin dimensions and selection of riprap.

Given a $Q_{100} = 400$ cfs and the following upstream and downstream channel dimensions:

- bottom width = 8 ft
- longitudinal slope = 0.004 ft/ft
- side slopes = 4:1
- y_c = 2.8 ft
- y_n = 4 ft
- v_n = 4.2 ft/s
- channel drop, C = 3 ft

From Table 5-10, for $C = 3.0$ ft, $v_n = 4.2$ ft/s (assume $v_n = 5$ ft/s on table), and y_n and $y_2 = 4.0$ ft, the following dimensions can be determined:

- P = 0.1 ft
- B = 1.0 ft
- A = 2.5 ft
- L_B = 20 ft
- D = 5 ft
- E = 4 ft
- Riprap = d_{50} of 18 inches

Table 5-10 Vertical Riprap Channel Drop Design Chart

C (ft)	v_n (ft/s)	y_n & y_2 (ft)	P (ft)	B (ft)	A (ft)	L_B (ft)	D (ft)	E (ft)	Riprap d_{50} (in)
2	5	4	0.1	0.6	2.0	20	4	3	12
2	5	5	*	0.8	2.5	25	5	4	18
2	5; 7	4	0.1	0.8	2.5	20	5	4	18
2	5; 7	5	*	0.8	2.5	25	5	4	18
3	5	4	0.1	1.0	2.5	20	5	4	18
3	5	5	*	1.0	2.5	25	5	4	18
3	5; 7	4	0.1	1.0	2.5	20	5	4	18
3	5; 7	5	*	1.0	2.5	25	5	4	18
4	5	4	0.1	1.2	3.5	20	7	5	18
4	5	5	*	1.2	3.5	25	7	5	18
4	5; 7	4	0.1	1.4	3.5	20	7	6	18
4	5; 7	5	*	1.4	3.5	25	7	6	18

* See crest wall elevation chart below

Crest Wall Elevation Chart

approach bottom width (ft)	P (ft) at $V_n = 5$ ft/s	P (ft) at $V_n = 7$ ft/s
5	0.2	0.2
4	0.4	0.2
100	0.5	0.3

Notes:

1. See Figure 5-6 for definition of symbols.
2. Maximum allowable C = 4.0 ft.
3. This chart is for ordinary riprap structures only. Other types of drop structures require their own hydraulic analysis.

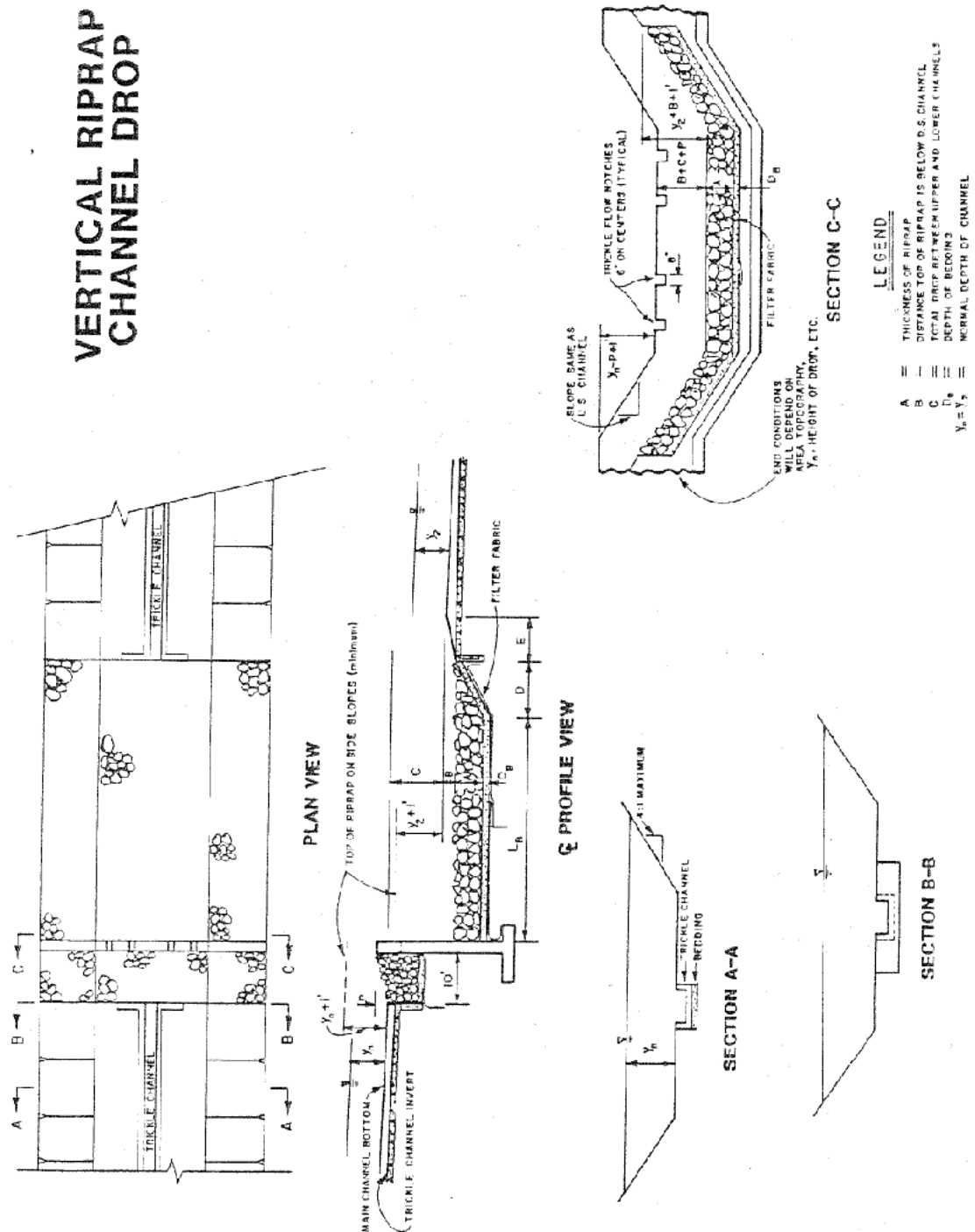


Figure 5-6 Vertical Riprap Channel Drop

Source: City of Tulsa, 1993

5.11 Stability And Bank Protection

5.11.1 Channel Stability Guidelines

The best way to avoid instability problems in urban stream channels and to maximize environmental benefits is to maintain streams in as natural a condition as possible, and when channel modification is necessary, to avoid altering channel dimensions, channel alignment, and channel slope as much as possible, except to account for impacts caused by urbanization. When channel modification is necessary, the following set of guidelines should be followed to minimize erosion problems and maximize environmental benefits.

- When channels must be enlarged, avoid streambed excavation that would significantly increase streambed slope or streambank height.
- When channel bottom widths are increased more than 25 percent, provide for a low flow channel to concentrate flows during critical low flow periods.
- Avoid channel realignment whenever feasible.

When unstable banks exist, several stabilization measures can be employed to provide the needed erosion protection and bank stability. The types of slope protection or revetment commonly used for bank stabilization include:

- turf reinforcement,
- rock and rubble riprap,
- wire-enclosed rock (gabions),
- pre-formed concrete blocks,
- grouted rock, and
- bioengineering methods
- poured-in-place concrete
- grout-filled fabric mattress

5.11.2 Rock Riprap

Placement of riprap is often used as bank or bed stabilization. Design of riprap size and thickness has been presented in numerous documents including those by Reese (1984 and 1988). Filter material is installed beneath riprap in all cases. Refer to the City of Lincoln standard specifications for material specification.

Filter Fabric Placement

To provide good performance, a properly selected cloth should be installed in accordance with manufacturer recommendations with due regard for the following precautions:

- Heavy riprap may stretch the cloth as it settles, eventually causing bursting of the fabric in tension. A 4-inch to 6-inch gravel bedding layer should be placed beneath the riprap layer for riprap gradations having d_{50} greater than 3.00 ft.
- The filter cloth should not extend into the channel beyond the riprap layer; rather, it should be wrapped around the toe material as illustrated in Figure 5-7.
- Adequate overlaps must be provided between individual fabric sheets.
- A sufficient number of folds should be included during placement to eliminate tension and stretching under settlement.
- Securing pins with washers are recommended at 2- to 5-ft intervals along the midpoint of the overlaps.
- Proper stone placement on the filter requires beginning at the toe and proceeding up the slope. Dropping stone from heights greater than 2 ft can rupture fabrics (greater drop heights are allowable under water).

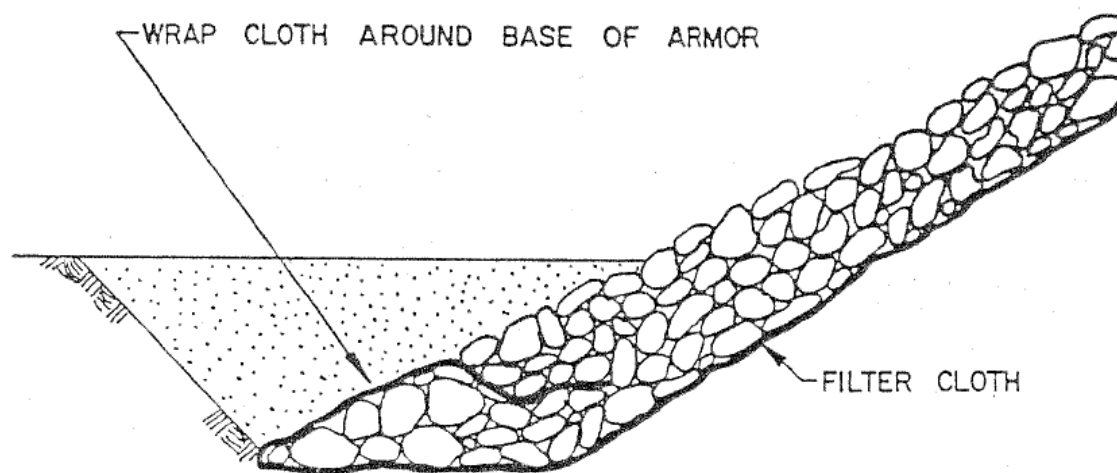


Figure 5-7 Filter Fabric Placement

5.11.2.1 Edge Treatment

The edges of riprap revetments (flanks, toe, and head) require special treatment to prevent undermining. The flanks of the revetment should be designed as illustrated in Figure 5-8. The upstream flank is illustrated in section (a) and the downstream flank is illustrated in section (b) of this figure. A more constructable flank section uses riprap rather than compacted fill.

Undermining of the revetment toe is one of the primary mechanisms of riprap failure. The toe of the riprap should be designed as illustrated in Figure 5-9. The toe material should be placed in a toe trench along the entire length of the riprap blanket.

Where a toe trench cannot be dug, the riprap blanket should terminate in a thick, stone toe at the level of the streambed (see alternate design in Figure 5-9). Care must be taken during the placement of the stone to ensure that the toe material does not mound and form a low dike; a low dike along the toe could result in flow concentration along the revetment face which could stress the revetment to failure. In addition, care must be exercised to ensure that the channel's design capability is not impaired by placement of too much riprap in a toe mound.

The size of the toe trench or the alternate stone toe is controlled by the anticipated depth of scour along the revetment. As scour occurs (and in most cases it will) the stone in the toe will launch into the eroded area. Observation of the performance of these types of rock toe designs indicates that the riprap will launch to a final slope of approximately 2:1.

The volume of rock required for the toe must be equal to or exceed one and one-half times the volume of rock required to extend the riprap blanket (at its design thickness and on a slope of 2:1) to the anticipated depth of scour. Dimensions should be based on the required volume using the thickness and depth determined by the scour evaluation. The alternate location can be used when the amount of rock required would not constrain the channel.

5.11.2.2 Construction Considerations

Construction considerations related to the construction of riprap revetments include bank slope or angle, bank preparation, and riprap placement.

The area should be prepared by first clearing all trees and debris, and grading the surface to the desired slope. In general, the graded surface should not deviate from the specified slope line by more than 6 inches. However, local depressions larger than this can be accommodated since initial placement of filter material and/or rock for the revetment will fill these depressions. In addition, any debris found buried near the edges of the revetment should be removed.

The common methods of riprap placement are hand placing; machine placing, such as from a skip, dragline, or some form of bucket; and dumping from trucks and spreading by bulldozer. Hand placement produces the best riprap revetment, but it is the most expensive method except when labor is unusually cheap. Steeper side slopes can be used with hand placed riprap than with other placing methods. Where steep slopes are unavoidable (when channel widths are constrained by existing bridge openings or other structures, and when rights-of-way are costly), hand placement should be

considered.

In the machine placement method, sufficiently small increments of stone should be released as close to their final positions as practical. Rehandling or dragging operations to smooth the revetment surface tend to result in segregation and breakage of stone, and can result in an overly rough revetment surface. Stone should not be dropped from an excessive height as this may result in the same undesirable conditions. Riprap placement by dumping with spreading may be satisfactory provided the required layer thickness is achieved. Riprap placement by dumping and spreading is the least desirable method as a large amount of segregation and breakage can occur and is not recommended. In some cases, it may be economical to increase the layer thickness and stone size somewhat to offset the shortcomings of this placement method.

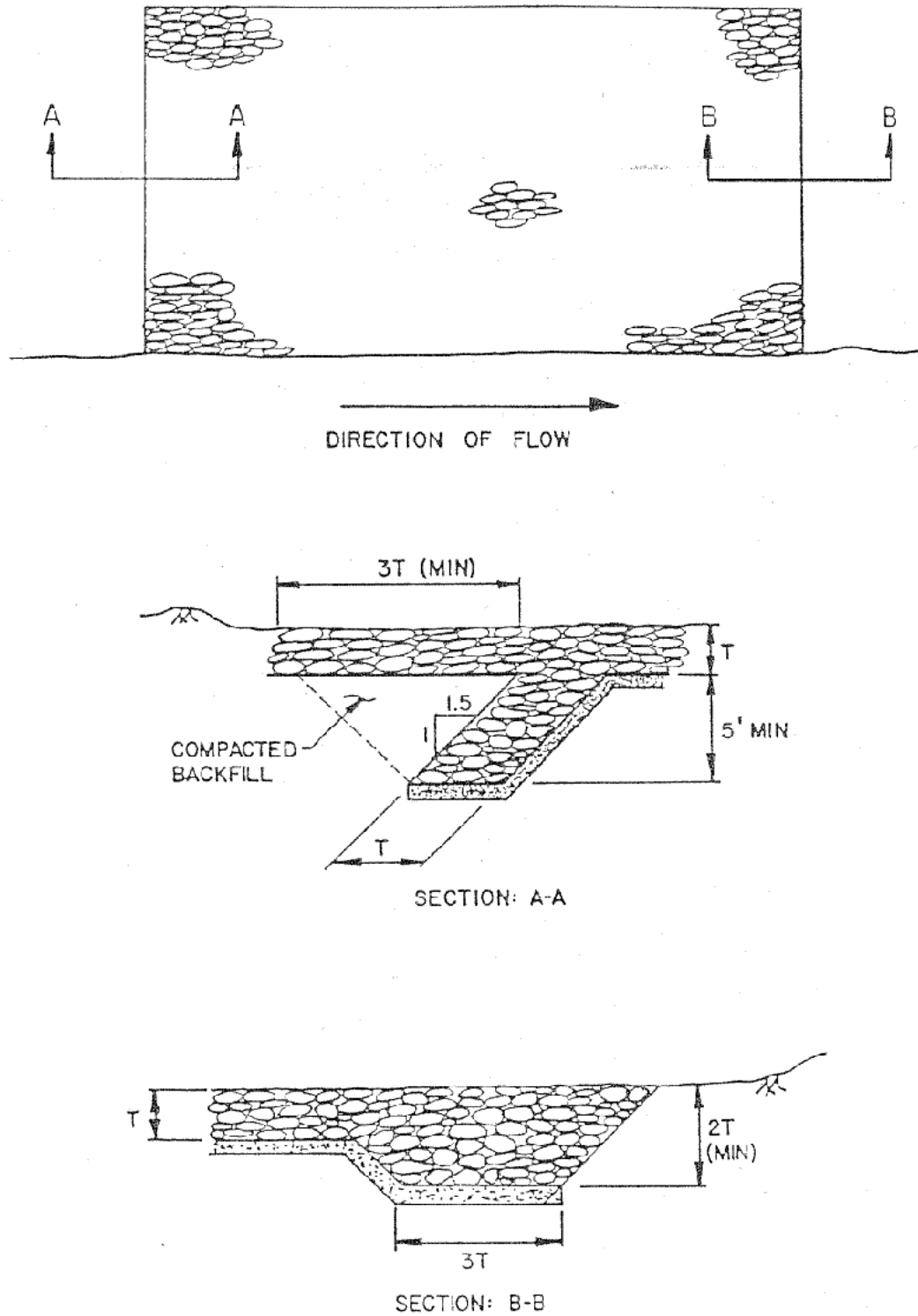


Figure 5-8 Typical Riprap Installation: Plan And Flank Details

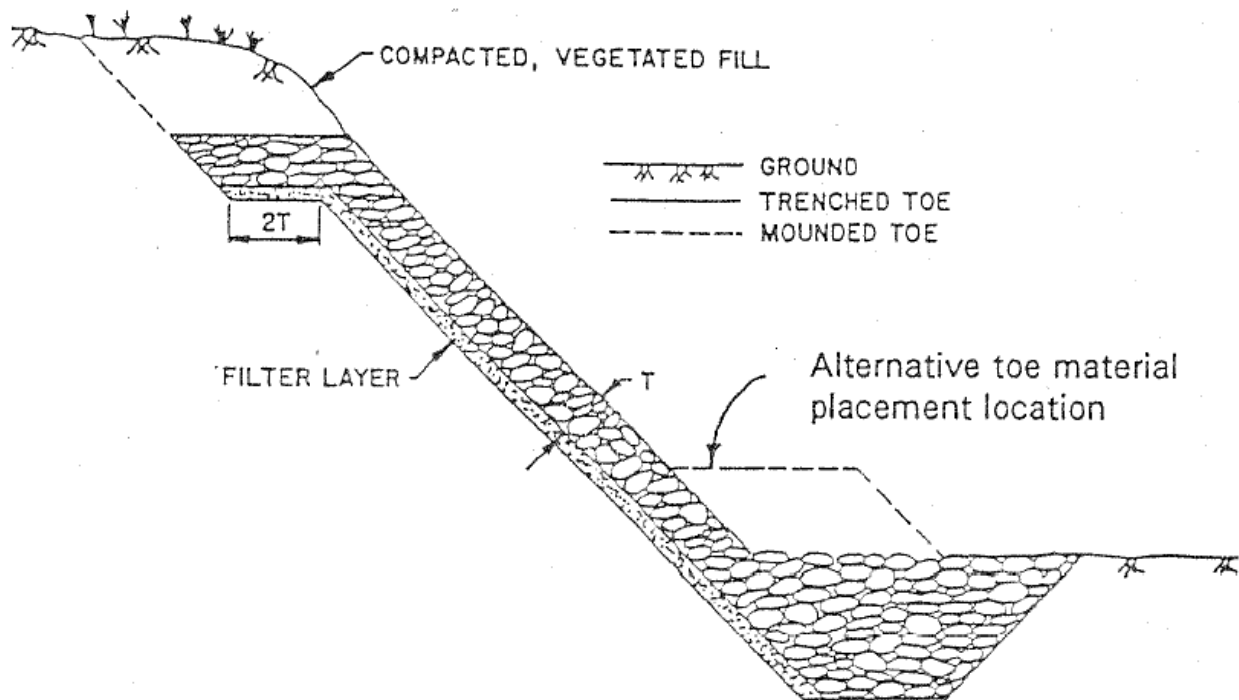


Figure 5-9 Typical Riprap Installation: End View (Bank Protection Only)

5.11.2.3 Design Procedure

The rock riprap design procedure outlined in the following sections is comprised of three primary sections: preliminary data analysis, rock sizing, and revetment detail design. The individual steps in the procedure are numbered consecutively throughout each of the sections.

Preliminary Data

Step 1 Compile all necessary field data including (channel cross section surveys, soils data, aerial photographs, history of problems at site, etc.).

Step 2 Determine design discharge.

Step 3 Develop design cross section(s). Note: The rock sizing procedures described in the following steps are designed to prevent riprap failure from particle erosion.

Step 4 Compute design water surface.

- (a) When evaluating the design water surface, Manning's "n" shall be estimated. If a riprap lining is being designed for the entire channel perimeter, an estimate of the rock size may be required to determine the roughness coefficient "n".
- (b) If the design section is a regular trapezoidal shape, and flow can be assumed to be uniform, use design procedures delineated in this chapter.
- (c) If the design section is irregular or flow is not uniform, backwater procedures must be used to determine the design water surface.
- (d) Any backwater analysis conducted must be based on conveyance weighing of flows in the main channel, right bank and left bank.

Step 5 Determine design average velocity and depth.

- (a) Average velocity and depth should be determined for the design section in conjunction with the computations of step 4. In general, the average depth and velocity in the main flow channel should be used.
- (b) If riprap is being designed to protect channel banks, abutments, or piers located in the floodplain, average floodplain depths and velocities should be used.

Step 6 Compute the bank angle correction factor $K_1 = [1 - (\sin^2 \theta / \sin^2 \Phi)]^{0.5}$. (5.8)

Where:

θ = the bank angle with the horizontal

Φ = the riprap material's angle of repose

Step 7 Determine riprap size required to resist particle erosion $d_{50} = 0.001 V^3 / d_{avg}^{0.5} K_1^{1.5}$. (5.9)

Where:

d_{50} = the median riprap particle size, ft

V = the average velocity in the main channel, ft/s

d_{avg} = the average flow depth in the main flow channel ft,

K_1 = bank angle correction factor

- (a) Initially assume no corrections.
- (b) Evaluate correction factor for rock riprap specific gravity and stability factor $C = C_{sg}C_{sf}$.

$$C_{sg} = 2.12 / (S_s - 1)^{1.5}$$

Where: S_s = the specific gravity of the rock riprap

$$C_{sf} = (SF / 1.2)^{1.5}$$

Where: SF = the stability factor to be applied

Step 8 If the entire channel perimeter is being stabilized, and an assumed d_{50} was used in determination of Manning's 'n' for backwater computations, return to step 4 and repeat steps 4 through 7.

Step 9 Select final d_{50} riprap size, set material gradation, and determine riprap layer thickness.

Step 10 Determine longitudinal extent of protection required.

Step 11 Determine appropriate vertical extent of revetment.

Step 12 Design filter layer.

- (a) Determine appropriate filter material size and gradation.
- (b) Determine layer thickness.

Step 13 Design edge details (flanks and toe).

5.11.3 Wire-enclosed Rock

Wire-enclosed rock (gabion) revetments consist of rectangular wire mesh baskets filled with rock. The most common types of wire-enclosed revetments are mattresses and stacked blocks. The wire cages which make up the mattresses and gabions are available from commercial manufacturers.

Rock and wire mattress revetments consist of flat wire baskets or units filled with rock that are laid end to end and side to side on a prepared channel bed and/or bank. The individual mattress units are wired together to form a continuous revetment mattress.

Stacked block gabion revetments consist of rectangular wire baskets which are filled with stone and stacked in a stepped-back fashion to form the revetment surface. They are also commonly used at the toe of embankment slopes as toe walls which help to support other upper bank revetments and prevent undermining.

The rectangular basket or gabion units used for stacked configurations are more equidimensional than those typically used for mattress designs. That is, they typically have a square cross section. Commercially available gabions used in stacked configurations are available in various sizes but the most common have a 3-ft width and thickness.

Follow manufacturers recommended practice for design of gabions.

5.11.4 Pre-cast Concrete Blocks

Pre-cast concrete block revetments consist of pre-formed sections which interlock with each other, are attached to each other, or butt together to form a continuous blanket or mat. The concrete blocks which make up the mats differ in shape and method of articulation, but share certain common features. These features include flexibility, rapid installation, and provisions for the establishment of vegetation within the revetment.

Pre-cast revetments are bound using a variety of techniques. In some cases the individual blocks are bound to rectangular sheets of filter fabric (referred to as fabric carrier). Other manufacturers use a design which interlocks individual blocks. Other units are simply butted together at the site. The most common method is to join individual blocks with wire cable or synthetic fiber rope. Follow manufacturers recommended design procedure.

5.11.5 Grouted Rock

Grouted rock revetment consists of rock slope-protection having voids filled with concrete grout to form a monolithic armor.

Components of grouted rock riprap design include layout of a general scheme or concept, bank preparation, bank slope, rock size and blanket thickness, rock grading, rock quality, grout quality, edge treatment, filter design, and pressure relief.

Grouted riprap designs are rigid monolithic bank protection schemes. When complete they form a continuous surface. A typical grouted riprap section is shown in Figure 5-10. Grouted riprap should extend from below the anticipated channel bed scour depth to the design high water level, plus additional height for freeboard.

During the design phase for a grouted riprap revetment, special attention needs to be paid to edge treatment, foundation design, and mechanisms for hydrostatic pressure relief.

Bank And Foundation Preparation

The area to be stabilized should be prepared by first clearing all trees and debris, and grading the surface to the desired slope. In general, the graded surface should not deviate from the specified slope line by more than 6 inches. However, local depressions larger than this can be accommodated since initial placement of filter material and/or rock for the revetment will fill these depressions.

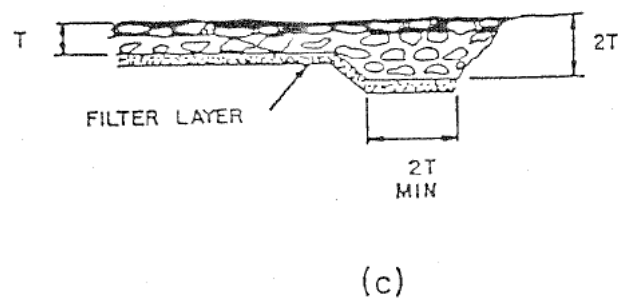
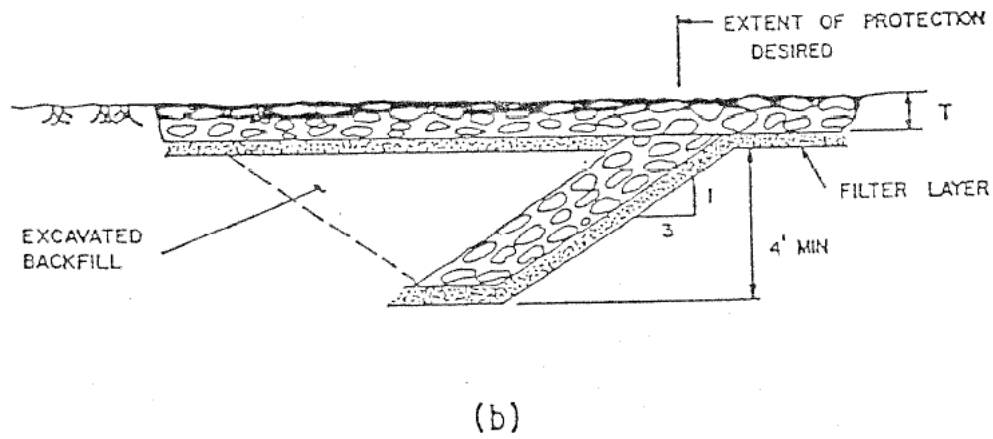
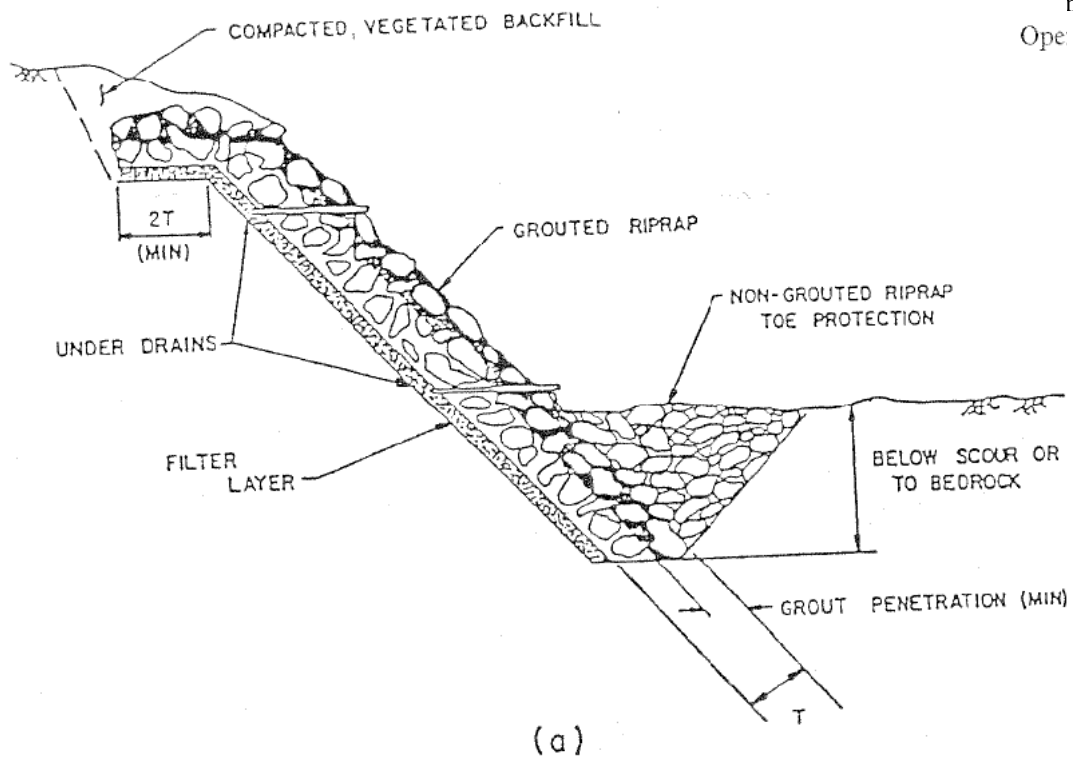


Figure 5-10 Grouted Riprap Sections: (a) Section; (b) Upstream Flank; and (c) Downstream Flank

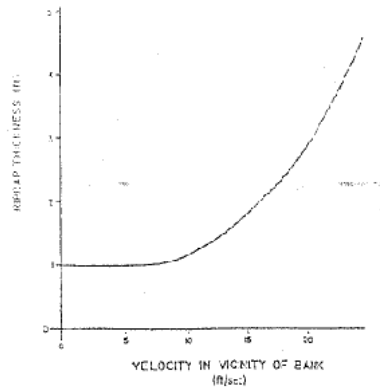


Figure 5-11 Required Blanket Thickness As A Function Of Flow Velocity

Since grouted riprap is rigid but not extremely strong, support by the embankment must be maintained. To form a firm foundation, it is recommended that the bank surface be tamped or lightly compacted. Care must be taken during bank compaction to maintain a soil permeability similar to that of the natural, undisturbed bank material. The foundation for the grouted riprap revetment should have a bearing capacity sufficient to support either the dry weight of the revetment alone, or the submerged weight of the revetment plus the weight of the water in the wedge above the revetment for design conditions, whichever is greater.

Bank Slope

Bank slopes for grouted riprap revetments should not exceed 1.5:1. The soil stability slope will likely determine the maximum bank slope.

Rock Size And Blanket Thickness

Blanket thickness and rock size requirements for grouted riprap installation are interrelated. Figure 5-11 illustrates a relationship between the design velocity and the required riprap blanket thickness for grouted riprap designs. The median rock size in the revetment should not exceed 0.67 times the blanket thickness. The largest rock used in the revetment should not exceed the blanket thickness.

Rock Grading

Grouted riprap should meet all of the requirements for ordinary riprap except that the smallest rock fraction (i.e., smaller than the 10 percent size) should be eliminated from the gradation. A reduction of riprap size by one size designation is acceptable for grouted rock.

Rock Quality

Rock used in grouted rock slope-protection is usually the same as that used in ordinary rock slope-protection. However, the specifications for specific gravity and hardness may be lowered if necessary as the rocks are protected by the surrounding grout. In addition, the rock used in grouted riprap installations should be free of fines in order that penetration of grout may be achieved.

Grout Quality And Characteristics

Grout should consist of good strength concrete using a maximum aggregate size of 3/4 inch and a slump of 3 to 4 inches. Sand mixes may be used where roughness of the grout surface is unnecessary, provided sufficient cement is added to give good strength and workability.

The volume of grout required will be that necessary to provide penetration to the full depth of the riprap layer or at least 2 feet where the riprap layer is thicker than 2 feet. The finished grout should leave face stones exposed for one-fourth to one-third their depth and the surface of the grout should expose a matrix of coarse aggregate.

Edge Treatment

The edges of grouted rock revetments (the head, toe, and flanks) require special treatment to prevent undermining. The revetment toe should extend to a depth below anticipated scour depths or to bedrock. The toe should be designed as illustrated in Figure 5-10(a). After excavating to the desired depth, the riprap slope protection should be extended to the bottom of the trench and grouted. The remainder of the excavated area in the toe trench should be filled with ungrouted riprap. The ungrouted riprap provides extra protection against undermining at the bank toe.

To prevent outflanking of the revetment, various edge treatments are required. Recommended designs for these edge treatments are illustrated in Figure 5-10, parts (a), (b), and (c).

Filter Design

Filters are required under all grouted riprap revetments to provide a zone of high permeability to carry off seepage water and prevent damage to the overlying structure from uplift pressures. A 6-inch granular filter is required beneath the pavement to provide an adequate drainage zone. The filter can consist of well-graded granular material or uniformly-graded granular material with an underlying filter fabric. The filter should be designed to provide a high degree of permeability while preventing base material particles from penetrating the filter, thus causing clogging and failure of the protective filter layer.

Pressure Relief

Weep holes should be provided in the revetment to relieve hydrostatic pressure build-up behind the grout surface (see Figure 5-10(a)). Seeps should extend through the grout surface to the interface with the gravel underdrain layer. Weeps should consist of 2-inch minimum diameter pipes having a maximum horizontal spacing of 6 ft and a maximum vertical spacing of 10 ft. The buried end of the weep should be covered with wire screening or a fabric filter of a gage that will prevent passage of the gravel underlayer.

5.11.5.1 Construction

Construction details for grouted riprap revetments are illustrated in Figure 5-10. The following construction procedures should be followed:

- Step 1 Normal construction procedures include (a) bank clearing and grading; (b) development of foundations; (c) placement of the rock slope protection; (d) grouting of the interstices; (e) backfilling toe and flank trenches; and (f) vegetation of disturbed areas.
- Step 2 The rock should be set immediately prior to commencing the grouting operation.
- Step 3 The grout may be transported to the place of final deposit by chutes, tubes, buckets, pneumatic equipment, or any other mechanical method which will control segregation and uniformity of the grout.
- Step 4 Spading and rodding are necessary where penetration is achieved by gravity flow into the interstices.
- Step 5 No loads should be allowed upon the revetment until good strength has been developed.

5.11.6 Bioengineering Methods

Bioengineering combines mechanical, biological, and ecological concepts to construct “living” structures for bank and slope protection. Bioengineering methods use structural support to hold live plantings in place while the root structure grows and the plants are established. This is done through the use of sprigging, live crib walls, cut brush layers, live fascines, live stakes, and other methods.

Advantages of bioengineering include: natural appearance, the self-healing properties, habitat enrichment, and resistance to slope failure. Disadvantages include: labor-intensive installation, need for stability control until the roots are established, and dependence on materials to root and grow. Bioengineering is gaining in popularity throughout the country, locally, the LPSNRD initiated a pilot project along Beal Slough near the 40th Street Bridge in 1997 that employed bioengineering techniques for bank stabilization.

Soil-bioengineered bank stability systems have not been standardized, the decision of whether and how to use the requires careful consideration. Two excellent references for detailed bioengineering design guidelines entitled “Stream Restoration: Principles, Processes, and Practices, Final Manuscript Draft, 1998” and “Part 650, Engineering Field Handbook, Chapter 16, Streambank and Shoreline Protection, 1996”, are published by the Natural Resources Conservation Service. The first document is available at www.usda.gov on the NRCS webpage for downloading. These documents provide background on fundamental concepts necessary for planning, designing and applying bio-engineering techniques on many streams. Expertise in soils, biology, plant sciences, landscape architecture, geology, engineering and hydrology may be required for projects where the stream is large or the erosion is severe (NRCS Stream Corridor Restoration Final Manuscript Draft 1998). Several examples of bio-engineering techniques are presented in Figures 5-12-through 5-18.

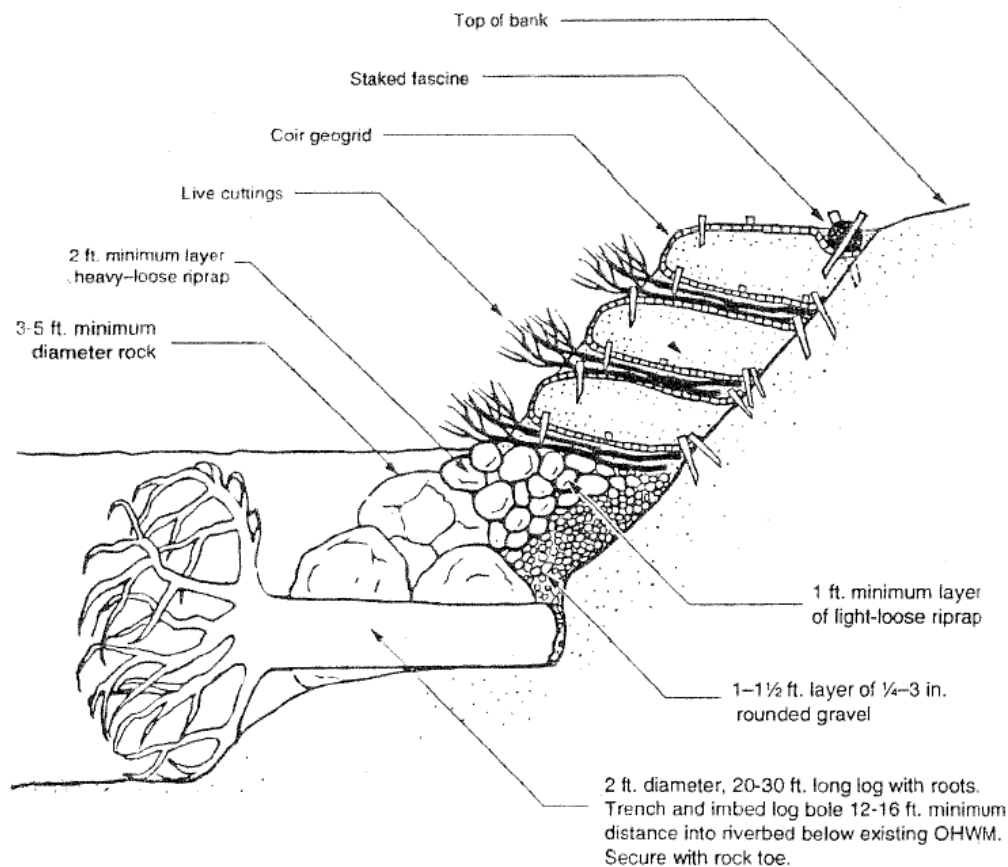


Figure 5-12 Integrated System with Large Woody Debris

Source: NRCS, 1996

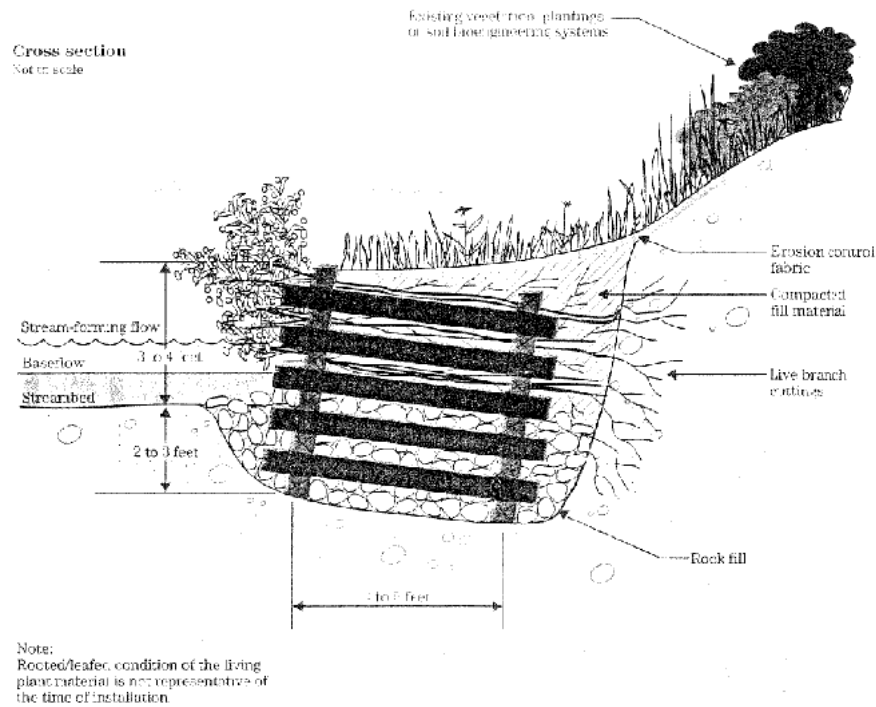


Figure 5-13 Live Cribwall Details

Source: NRCS, 1996

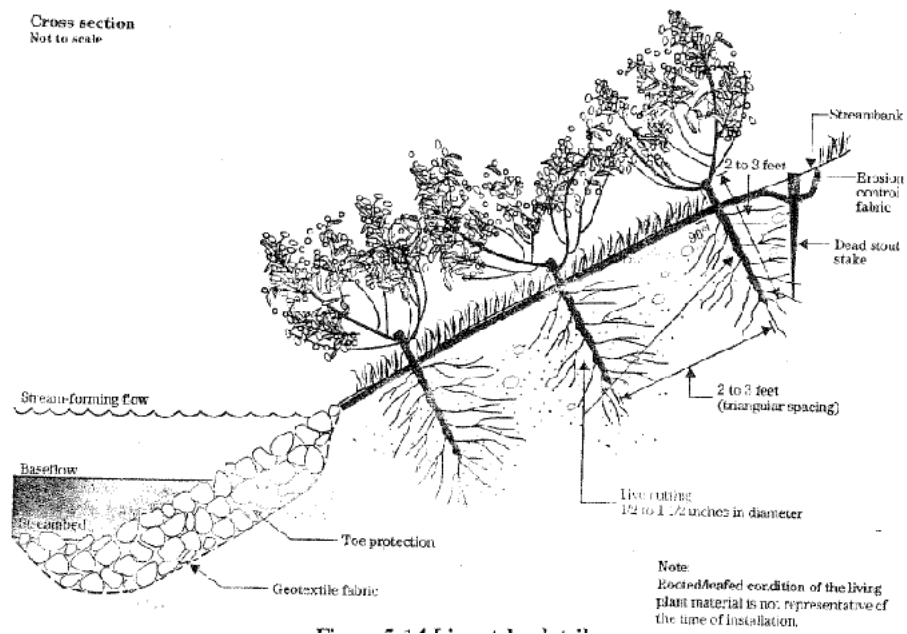


Figure 5-14 Live stake details

Source: NRCS, 1996

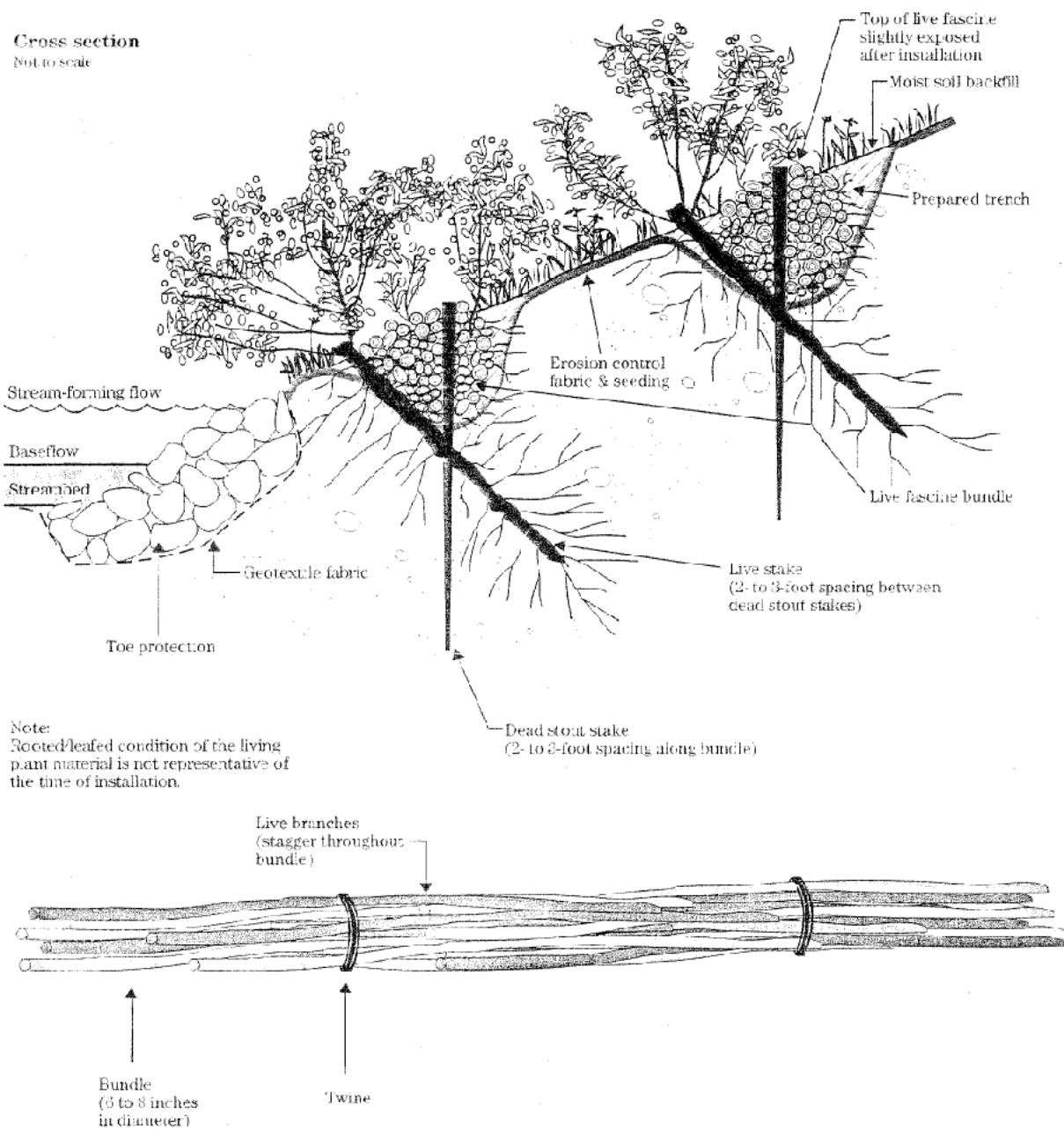


Figure 5-15 Live fascine details

Source: NRCS, 1996

Cross section
Not to scale

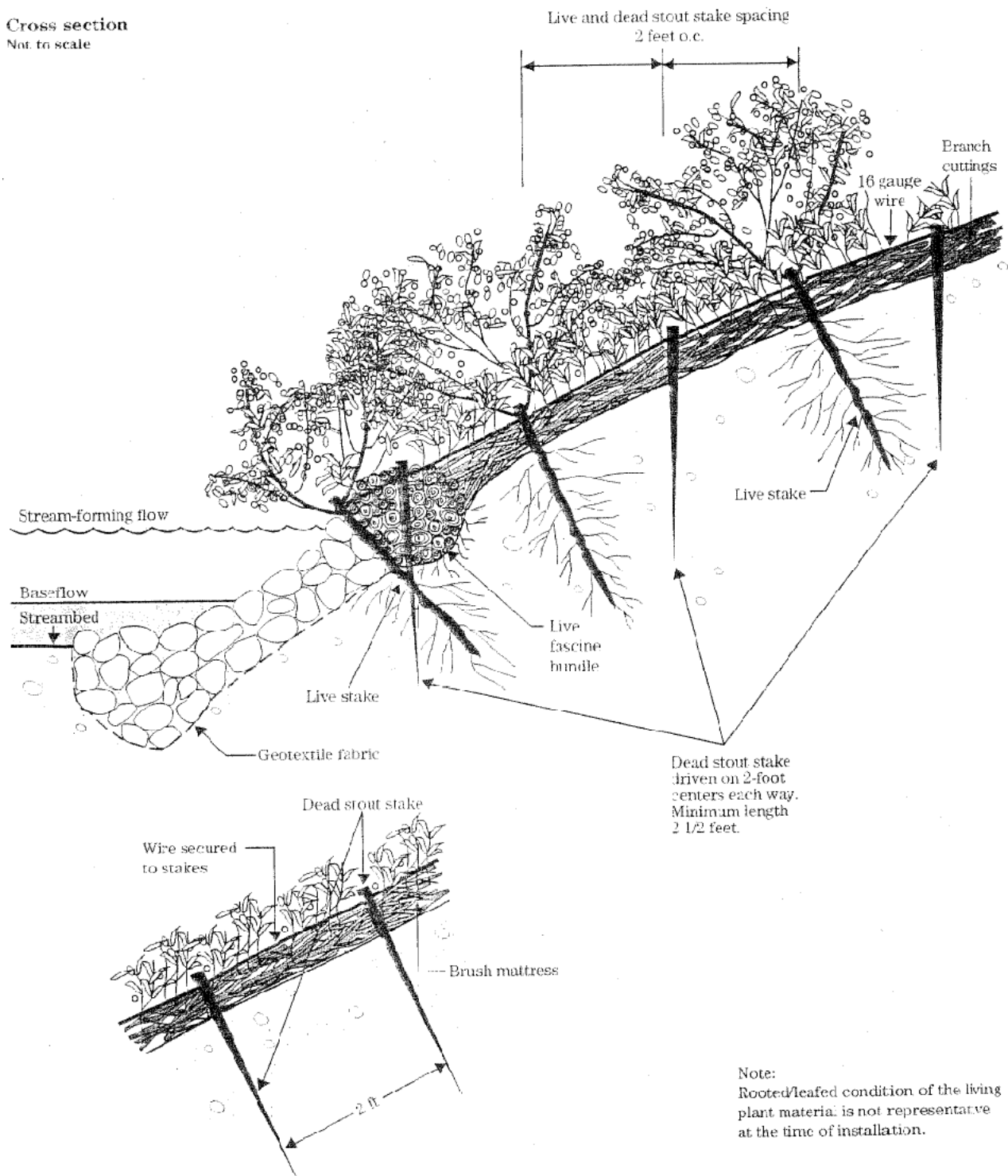


Figure 5-16 Brushmattress details

Source: NRCS, 1996

Open Channels

Open Channels

Note: Rooted/leafed condition of the living plant material is not representative of the time of installation.

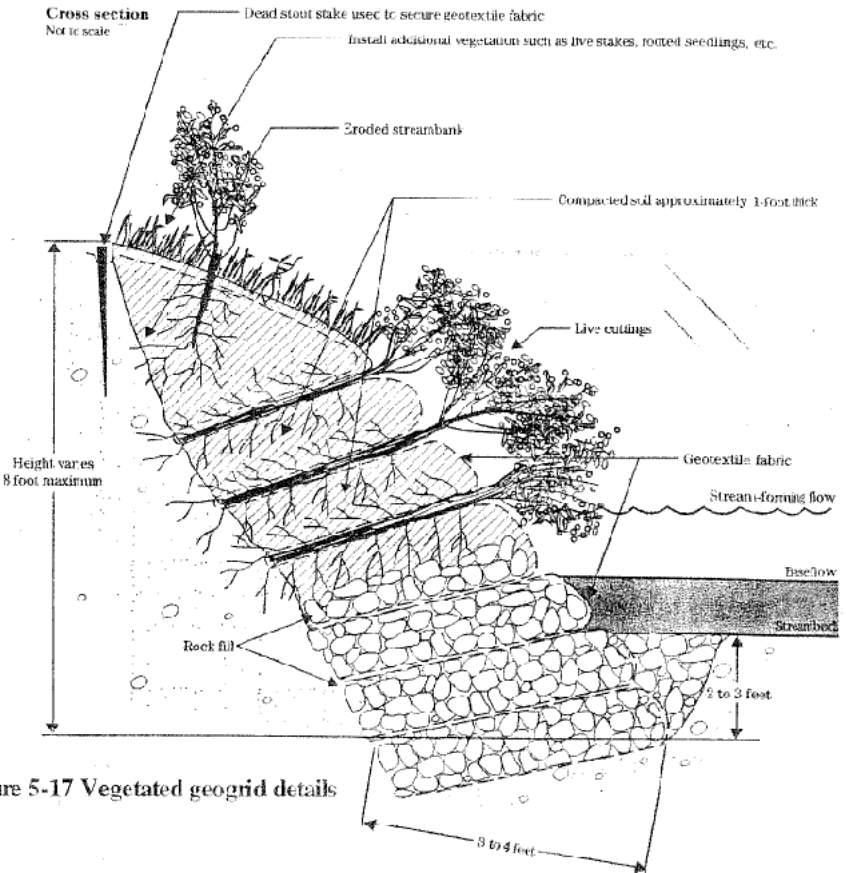


Figure 5-17 Vegetated geogrid details

Source: NRCS, 1996

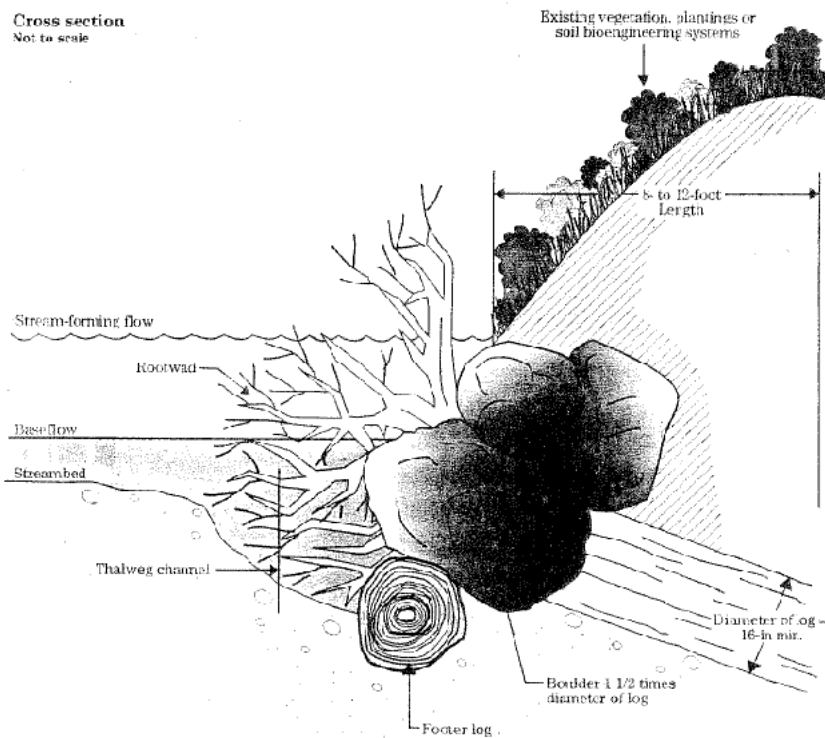


Figure 5-18 Log, rootwad, and boulder revetment details

Source: NRCS, 1996

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